seismal lines in these directions, and (2) by the greater prominence of the sound in the south-east part of the disturbed area and of the shock in the north-west part.

After two or three seconds there appears (from the double character of the shock) to have been a second and slighter slip, probably at a short distance to the north-west of the former.

History of the Charnwood Forest Fault.—The greater part of the displacement along the anticlinal fault seems to have taken place in pre-Carboniferous times, leaving only a few hundred feet to be accomplished in subsequent periods.* Earthquakes in the Charnwood district are now extremely rare. Between December 23, 1838, and August 4, 1893, we have not one recorded.† The shocks of the present century thus indicate at how slow a rate the fault is now growing. They also show that that growth has not yet ceased, and enable us to form some conception of the vast interval of time over which the life of a fault may extend.

"On the Different Forms of Breathing." By William Marcet, M.D., F.R.S. Received June 12,—Read June 21, 1894. Revised September 7, 1894.

I must beg leave at the outset to acknowledge the valuable aid of my Assistant, Mr. R. B. Floris, F.C.S., in the present inquiry. An investigation of this kind, necessitating much consideration, can only be carried to a successful issue by arguments and discussions, and to Mr. Floris much credit is due for the light these discussions have shed on the inquiry; I feel also indebted to him for the care he has bestowed on the numerous analyses he has made for me, and for the accuracy with which his work has invariably been done.

From a general view of the function of respiration it follows that there are four fundamental forms of breathing; their characters are the following:—

1st. Normal breathing in the state of repose—a regular succession of the respiratory movements, involuntary, unattended with fatigue, and leaving an approximately unchanged balance between the CO_2 in store, in the blood, and the CO_2 expired.

2nd. Forced breathing—a voluntarily increased thoracic expansion, brought about by the contraction of muscles differing more or less from those in common use in respiration and attended with fatigue. The expiration of carbonic acid is increased beyond the normal;

* 'Quart. Journ. Geol. Soc.,' vol. 34, 1878, p. 232.

† W. Roper, 'A List of the more remarkable Earthquakes in Great Britain and Ireland during the Christian Era' (Lancaster, 1889), pp. 34—42.

though not from excessive oxidation, with the exception of a small amount due to the extra work of the respiratory muscles.

3rd. Respiration *under exercise*—increased volumes of air inspired and expired in a given time with an expiration of CO_2 in excess of the CO_2 expired in repose, and unattended with fatigue. At the same time there occurs an increase of the CO_2 in store in the blood, which takes place with a certain regularity during the first fifteen or eighteen minutes after exercise has begun, and is irregular afterwards. This excess of stored up CO_2 is given out as soon as exercise is followed by repose.

4th. The fourth form of breathing is under the influence of volition, when exerted in a person's imagination towards a powerful muscular exertion, while the muscles are in a perfect state of repose. This form of breathing exhibits the characters of forced respiration and respiration under exercise.

These four different forms of breathing have received special attention, and will, collectively, be found to include every variety of respiration. They have been recorded graphically in the charts which accompany the present paper. By means of a drum revolving regularly by clockwork, and of a style at the end of a rod fixed to the summit of the bell-jar into which the air was expired, tracings were obtained on lithographed charts. The abscissæ on the charts indicate the litres of air expired, and the ordinates the minutes through which the experiment was continued.

The air expired was analysed, either for the determination of its CO_2 alone, or of its CO_2, O, and N; the volume of nitrogen obtained yielded by a simple proportion the volume of air inspired.

I shall now beg to give an account of my inquiry on these different forms of respiration.

1*st*. *Normal Breathing in the State of Repose.*

The methods adopted in the present work have been fully described elsewhere; as time elapsed improvements were introduced, and this last year the bell-jars used for collecting the expired air, instead of being exactly balanced as in former experiments, had their counterpoise charged in such a way as to give a slight ascending motion to the receivers when in free communication with the atmosphere, the speed they acquired being rather less than would be produced by the rush of air owing to the expiratory effort. Thus, the respiration was unattended with the unconscious strain necessary to raise the bell-jar while perfectly balanced. This effort, although unnoticed at the time, had a slight tendency to bring on after a while a sensation of fatigue in the respiratory muscles, and probably to increase, though to a very small amount, the volume of

CO_2 expired; at the same time the percentage of CO_2 in that air was somewhat greater than might have been anticipated. The present arrangement made away with that slight defect. It should be understood that the person under experiment while inspiring through the nose, first expired through a tube into the open air, then by means of three-way stop-cocks was placed in communication with either of the three bell-jars, used in these experiments; thus, the bell-jar only began ascending when the air was expired, while, during the period of inspiration, the mouth-piece retained in the mouth entirely checked any ascending tendency of the receiver.

This last season (1893–94), both I and Mr. Floris submitted to experiment for the determination of our carbonic acid expired and oxygen absorbed (not given out as CO_2) in the state of repose. In my case eleven experiments were made from 2 hours to $2\frac{1}{2}$ hours after luncheon (chop, potatoes, and bread), while four others were undertaken within 1 hour and 5 minutes after lunch. The results are as follows:—

The Author, from 2 hours to 2 hours and 30 mins. after Luncheon.
Per minute.

Time after luncheon.			CO_2 expired.	O absorbed.	O consumed.
	h.	m.	c.c.	c.c.	c.c.
	2	0	216·0	32·7	248·7
	2	5	210·9	36·0	246·9
	2	0	209·4	36·3	245·9
	2	5	206·4	52·1	258·5
	2	0	200·2	45·0	245·2
	2	20	192·1	34·9	227·0
	2	30	188·7	34·0	222·7
	2	20	184·4	38·2	222·6
	2	15	175·5	27·7	203·2
	2	20	175·4	32·1	207·5
	2	0	163·5	37·6	201·1
Means..	2	10	192·9	37·0	229·9
Respiratory ratio .... $\left\{\frac{192\cdot9}{229\cdot9}\right. = 0\cdot839.$					

The four experiments made within 1 hour and 5 minutes after luncheon are shown in the next table.

From these two series of experiments it will be observed that less CO_2 is expired during the first hour after a meal than from 2 to $2\frac{1}{2}$ hours, but there is considerably more oxygen absorbed within the first hour than from 2 to $2\frac{1}{2}$ hours after the ingestion of food, the proportion of 54·4 c.c. to 37 c.c. is a clear indication that such is the case.

The Author, within 1 hour and 5 mins. after Luncheon.

Time after luncheon.			CO_2 expired.	O absorbed.	O consumed.
	h.	m.	c.c.	c.c.	c.c.
	0	45	159·7	47·9	207·6
	0	25	203·8	55·6	259·4
	0	45	181·2	55·8	237·0
	1	5	191·8	58·3	250·1
Means..	0	45	184·1	54·4	238·5

Respiratory ratio .... $\left\{\frac{184 \cdot 1}{238 \cdot 5}\right. = 0 \cdot 772$

The experiments on Mr. Floris are made partly after luncheon and partly between breakfast and luncheon. There are fifteen of the former and twelve of the latter. The experiments after lunch show more CO_2 expired than those made after breakfast, and considerably more O absorbed, the figure for the mean volumes of oxygen absorbed being 40·5 c.c. after luncheon, and only 22·4 c.c. after breakfast.

If we now compare with each other the present series of experiments made individually for each of us, it will be seen that in those undertaken at a mean time of 2 to $2\frac{1}{4}$ hours after luncheon, the ratio of O consumed to CO_2 produced is all but exactly the same, these figures being 0·839 in my case and 0·840 in that of Mr. Floris. Moreover, if the whole of the experiments on Mr. Floris be taken into account, including those after luncheon and after breakfast, the respiratory ratio will be 0·862, which is all but exactly the figure I formerly obtained for myself, 0·864 (means fasting and under food), and near to the figure for a former assistant, 0·875, these results agreeing closely with the ratio given by Messrs. Jolyet Bergonié et Sigalas, 0·864, and by Mr. C. Speck, 0·869.

While in the experiments reported in my last paper, the volume of oxygen consumed in a certain time was nearly the same for each individual person (one excepted) under similar physical circumstances, in the present instance there is a variation between the volumes of oxygen consumed, the extreme difference amounts in my case to 47·6 c.c., in that of Mr. Floris to 30 c.c. per minute. Moreover, we no longer observe, as formerly, that the oscillations in the figures for carbonic acid expired, and corresponding oxygen absorbed vary in a measure inversely to each other. After giving the question a full consideration, I have come to the conclusion that this is due to the method of collecting the air expired. In the former experiments this air was expired into a bell-jar perfectly balanced under atmospheric pressure, while in the present instance the air was

Mr. Floris under Experiment.

After Breakfast—Fish or bacon or eggs, tea or coffee. After Luncheon—Mutton chop, potatoes, bread.

Per minute.

Time after breakfast.		CO_2 expired.	O absorbed.	O consumed.	Time after luncheon.		CO_2 expired.	O absorbed.	O consumed.
h.	m.	c.c.	c.c.	c.c.	h.	m.	c.c.	c.c.	c.c.
1	15	218·9	29·1	248·0	2	5	228·1	41·5	269·6
2	0	218·5	31·6	250·1	2	17	227·1	33·7	260·8
2	5	203·5	28·5	232·0	1	55	226·3	34·6	260·9
1	30	193·2	16·9	210·1	2	35	219·7	32·7	252·4
3	0	192·7	32·4	225·1	2	20	216·5	46·1	262·6
3	0	191·3	22·6	213 9	2	8	215·8	41·5	257·3
2	30	189·5	10·1	199·6	2	30	215·4	39·0	254·4
2	20	188·0	28·8	216·8	2	15	211·1	36·9	248·0
2	15	187·8	12·7	200·5	2	20	209·6	35·7	245·3
3	0	185·6	23·6	209·2	2	30	208·2	29·1	237·3
4	0	173·8	14·1	187·9	0	15	207·2	42·7	249·9
2	30	171·2	18·7	189·9	3	0	205·9	37·0	242·9
					2	24	200·3	57·7	258·0
					1	50	199·3	50·1	249·4
					3	0	190·9	48·8	239·7
Means 2	27	192·8	22·4	215·3	Means 2	15	212·1	40·5	252·6

Respiratory ratio after breakfast $\frac{192{\cdot}8}{215{\cdot}3} = 0{\cdot}895$.

Respiratory ratio after luncheon $\frac{212{\cdot}1}{252{\cdot}6} = 0{\cdot}840$.

Total mean respiratory ratio $\frac{203{\cdot}5}{236{\cdot}0} = 0{\cdot}862$.

expired into bell-jars with weighted counterpoise, as previously explained. With the balanced bell-jar there was a slight amount of work done which gave the breathing a degree of steadiness wanting with the counterpoise weighted; in the former experiments the very slight, though imperceptible, effort to raise the bell-jar gave regularity to the respiratory function. It must be recollected that during the day time, sitting perfectly quiet in an arm-chair, from a quarter of an hour to an hour, is altogether unnatural in ordinary life. We are always in a state of activity, and therefore the slight effort to raise the balanced bell-jar is perhaps more consistent with the ordinary functions of life than breathing perfectly freely, doing practically no work, indeed breathing much as we do at night in bed and during sleep. I therefore believe that the irregularity in the present figures obtained for the composition of expired air does not militate in any way against my former conclusion.

The next subject for our consideration will be

Forced Breathing.

Let us follow the different stages of this form of respiration. The person under experiment is resting in the recumbent posture and perfectly still, he then takes a succession of *deep* nasal inspirations while expiring through the mouth into one of the bell-jars. After a certain time, say one, two, or three minutes, he suddenly relapses into natural automatic breathing, and then observes that his respiration subsides for a few seconds into a pause or state of apnœa; by degrees it returns, shallow and feeble, and then fuller, increasing beyond the normal. If the apnœa has been great, the increase is well marked, but if comparatively slight the increase may be only just perceptible. These characters are invariably met with in every instance of "forced breathing" and are clearly shown by the tracings recorded in the charts. The phenomenon may be conveniently illustrated by means of the following diagram—

The horizontal line AA represents normal respiration, the curve AB the line of forced breathing, the curve BC the collapse in the respiration or apnœa, and gradual return to normal,* which it exceeds in CD, reaching finally the normal in D.

With reference to the respiratory changes in these three successive stages:—In the forced period, or from A to B, much more CO_2 is

* This return to normal only concerns the CO_2, the O absorbed takes a longer time to recover.

found to be given out of the blood than can be accounted for by the oxygen consumed, or, in other words, the volume of air expired exceeds in a marked degree the volume of air inspired. Where can the excess of CO_2 come from? It is evidently due to an emission from the blood of a portion of CO_2 stored up within it. This view is advocated by C. Speck in his paper, which has been referred to in my last communication. It will be shown presently that a further and more direct proof of this interesting fact can be experimentally given.

Until tracings of the phenomenon had been obtained on the recording drum, I thought the return to normal respiration was effected at the point C in the diagram, assuming that from B to C the blood recovered its CO_2 entirely and replenished its store; but as soon as tracings were obtained it became obvious that the final return to normal breathing failed to take place at C, and that the influence of the forced breathing continued to show itself as far as the point D.

This influence may appear consistent with the observation of C. Speck, who allies the "after stage" of forced breathing to the "after stage" of breathing under exercise; but the phenomenon appears to me to be strictly a character of forced respiration, inasmuch as it begins with apnœa, passing gradually into slightly increased breathing.

In the following table the CO_2 entered as *expired in forced breathing* is the total CO_2 expired from A to D in the diagram, and includes, therefore, the CO_2 expired in forced breathing plus the CO_2 emitted in the stage of apnœa and that obtained in the final reaction from C to D; the whole volume being calculated per minute.

It will be observed that the volumes of CO_2 in the experiments in forced breathing (including after stage) invariably exceed the volumes of CO_2 obtained in the same lapse of time during rest; this excess, which is entered in the table for each experiment, must represent the work done per minute in forced breathing.

The mean amount of this work done per minute would be equal to a combustion yielding 62·5 c.c. CO_2 for the author, and 47·5 c.c. CO_2 for Mr. Floris, corresponding to a consumption of carbon of 0·034 gram per minute for the author and 0·025 gram per minute for Mr. Floris.

The subject is further developed in the appendix to this paper.

A great deal more CO_2 is expired in *forced respiration* independently of the reaction and after stage than in ordinary breathing, and I shall now beg to demonstrate experimentally that this excess of expired CO_2 is from the store of absorbed CO_2 in the blood (with the exception of the small proportion for work done) and not a product of oxidation.

In order to attain that object, air forcibly inhaled was expired into three different bell-jars in succession, the air being diverted

Results of Experiments on Natural Breathing in Repose, and Forced or Laboured Respiration.

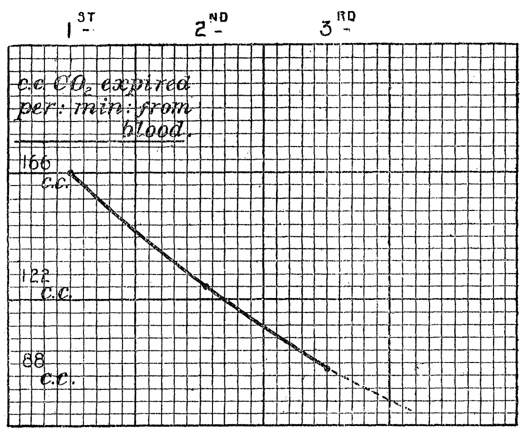
The Author under Experiment.

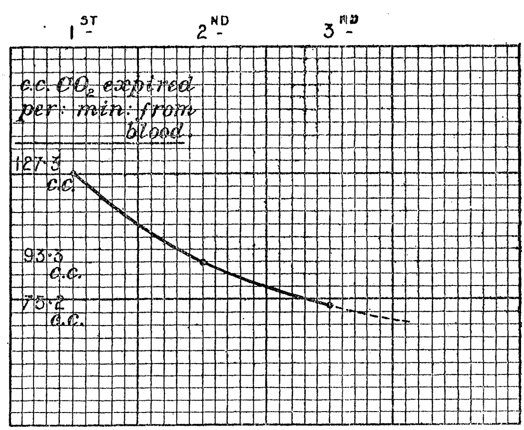
Normal respiration in repose per minute.				Forced or laboured respiration per minute.			
Time after lunch.	CO_2 expired normal.	Vol. air expired normal.	Vol. CO_2 for 100 air expired normal.	CO_2 expired in forced breathing.	Vol. air expired in forced breathing.	Vol. CO_2 for 100 air expired forced.	Excess CO_2 expired in forced breathing.
h. m.	c.c.	litres.	c.c.	c.c.	litres	c.c.	c.c.
2 30	188·2	4·859	3·87	253·8	6·652	3·81	65·6
0 25	203·8	5·120	3·97	311·8	8·267	3·77	108·0
2 20	192·1	4·524	4·24	262·1	6·512	4·02	70·0
2 35	191·1	4·962	3·85	245·6	5·996	4·10	46·5
0 45	159·7	4·033	3·95	204·0	5·275	3·87	44·3
2 0	200·2	4·801	4·17	240·9	5·860	4·11	40·7
Means	189·2	4·716	4·01	253·8	6·427	3·95	62·5

Mr. Floris under Experiment.

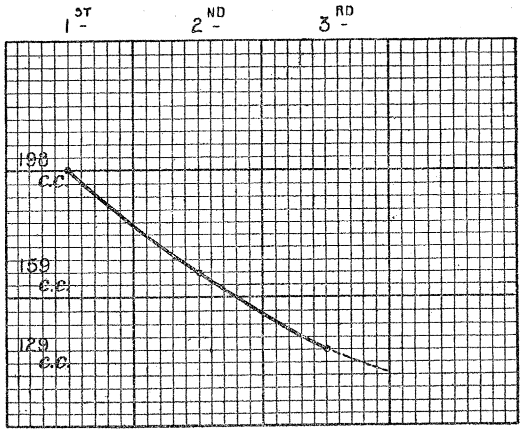
Time after lunch.	CO_2 expired normal.	Vol. air expired normal.	Vol. CO_2 for 100 air expired normal.	CO_2 expired in forced breathing.	Vol. air expired in forced breathing.	Vol. CO_2 for 100 air expired forced.	Excess CO_2 expired in forced breathing.
h. m.	c.c.	litres	c.c.	c.c.	litres	c.c.	c.c.
2 20 (after lunch)	209·6	4·357	4·81	251·1	5·345	4·70	41·5
2 30	215·4	4·133	5·21	270·0	5·517	4·89	54·6
2 30 (after breakfast)	187·8	3·842	4·89	229·6	4·917	4·67	41·8
1 30	193·2	3·894	4·96	248·0	5·089	4·88	54·8
2 30	189·5	3·889	4·87	234·4	5·085	4·61	44·9
Means	199·1	4·023	4·95	246·6	5·191	4·75	47·5

from one air holder to another by means of stopcocks; thus forced air expired in three successive periods of three minutes each was collected without undergoing the slightest loss. If the excess of CO_2 expired in forced breathing is really taken from that stored up in the blood, then it will be obvious that the second quantity of forced air expired will contain less CO_2 than the first, and the third quantity less than the second; moreover, the difference will be less and less as the experiment progresses, resulting in a curve of a parabolic form.* The experiment fully proved the correctness of the theory, three experiments for the author giving the following curves:—





* As the volumes of CO_2 expired from the blood-store depended on the volumes of air inspired (or expired), the CO_2 expired was calculated for the mean volumes of air expired in the three different bell-jars; by this means the volumes of CO_2 obtained in those different bell-jars could be correctly compared with each other.



The results obtained for Mr. Floris were as follows :—

CO_2 emitted per minute.	1st Expt.	2nd Expt.	3rd Expt.	4th Expt.
In first three minutes ..	271 c.c.	263 c.c.	327 c.c.	345 c.c.
In second ditto........	209 „	203 „	249 „	286 „
In third ditto	165 „	153 „	179 „	254 „

There can be no doubt, therefore, that the excess CO_2 expired in forced breathing is a result of diffusion through the moist pulmonary membrane of some of the CO_2 stored up in the blood. Forced breathing is concerned in sighing, yawning, and sneezing.

Breathing under Muscular Exercise.

The third form of breathing is under muscular exercise when an increased volume of air is breathed and a larger volume of CO_2 expired than in a state of repose. It has been shown in my last paper that the mean volume of oxygen, absorbed (not transformed into CO_2), at all events within a few minutes (from 15 to 18 minutes) after exercise has commenced, is the same as in the state of repose, or nearly so; this I have confirmed by more recent experiments, which, however, are not included in the present work. The increased action of the respiratory muscles under exercise is involuntary, unattended with fatigue, and differs in these respects from forced breathing. Again, in muscular exercise there is no apnœa or reaction after the exercise is arrested; on assuming a state of repose the breathing continues for a short time much the same as during

exercise, and then gradually returns to the normal. This "after stage" of muscular exercise is attended with a feeling of breathlessness, due mainly to the CO_2 accumulated in the blood during exercise. By increased expansion of the lungs, it soon finds its way into the air inspired, and is thus removed from the blood.

The tracing obtained on the chart for muscular exercise is steeper than that for breathing in the state of repose; on the person under experiment assuming the recumbent posture in an armchair, the tracing will be observed to be somewhat prolonged, then it straightens, parallel with the tracing for breathing in repose.

In none of these curves are there any signs of the reaction of forced breathing.

Muscular exercise of every kind, including singing, reading, talking, laughing, weeping, gives the same kind of tracing on the chart, though of course more or less steep, as will be seen in the accompanying curves. But in such kinds of exercise as singing, reading, talking, &c., which are not followed by breathlessness, it will be seen that the curve is either not prolonged at all, or but very slightly after the exercise is over, returning quickly to the normal; and showing that in these cases the CO_2 is emitted as fast as it is formed, or nearly so, little or none being detained in the blood.

There are passive forms of exercise which also increase the volume of air breathed and produce an excess of carbonic acid, such as friction of the skin, and cutaneous irritation. On the author's bare legs being rubbed hard by two persons, the volume of air he expired increased per minute from 3·892 litres to 4·441 litres, and the volume of CO_2 from 182·6 c.c. to 208·6 c.c. It may be therefore concluded that "shampooing" is really a form of exercise, as it must be productive of increased combustion. The application of a mustard leaf to each leg, causing a powerful degree of smarting, gave rise to a similar effect on the respiration; the volume of air breathed was increased per minute in one experiment from 4·719 litres to 5·099 litres, and the CO_2 from 189·4 c.c. to 226·7 c.c.

Breathing under the Influence of the Will.

The fourth form of breathing is while under the influence of the *will*. It had occurred to me to inquire whether the *will* without muscular exercise was attended with an increased volume of air breathed and a simultaneous excess of CO_2 expired. The experiment was carried out as follows. The person under experiment rested for a while in the recumbent posture in the deck chair, and then expired naturally into the bell-jar connected with the recording instrument, thus a tracing of his normal breathing was obtained. Then he commenced applying the will as he thought best, either to

carry a heavy weight, or to run up hill pursuing another person, or to ride a bicycle up hill, or in any other form, care being taken to keep the muscles absolutely at rest, when the result was invariably an increase in the volume of air expired, as shown in the chart. On suddenly dropping the influence of the will, and relapsing into the usual state of mind, a slight reaction was visible on the chart recalling forced breathing. The line, however, is straighter, and nearly free from the after rise observed in forced breathing, thus exhibiting a slight tendency to the form of curve peculiar to breathing under exercise.

Let us now inquire more closely into the present form of breathing. The moment the will is applied, as stated above, there is an increase in the volume of air breathed. What is the reason of this phenomenon? It must result from one of two different causes or from both—either an increased demand of oxygen by the blood, or the acquired habit of breathing more air while under an exercise which is itself controlled by the *will.* The increased action of the respiratory muscles when influenced by an effort of the will is *absolutely automatic;* there is no strain, no effort of any kind recalling forced breathing. Together with a greater volume of air breathed per minute we observe a marked increase of CO_2 produced and expired —an increase which amounts to a mean of 20·9 c.c. per minute. These 20·9 c.c. of CO_2 can only be due either to increased labour in the act of breathing, or increased combustion from the effect of the will, or to both these causes. The increased respiratory labour which is unconscious and unattended with fatigue must be very slight, and to my mind cannot account for 20·9 c.c. of CO_2 per minute; moreover, if the fact be taken into account that the increased volume of air breathed under an effort of the will points distinctly to a demand of oxygen from the air by the blood, and an increased production of CO_2 which has to be emitted, we shall be more and more convinced that volition (powerfully exerted) is productive of carbonic acid.

If we now turn our attention to the graphic illustration of breathing under a strong exertion of the will, we observe that the apnœa is somewhat less marked than in forced breathing, the curve straightening and thus approaching that of respiration under muscular exercise.

Taking into account the whole of the above considerations, it appears to me that we are justified in concluding, as it were from circumstantial evidence, in the absence of direct proof, that oxygen is absorbed and carbonic acid formed in the body from the mental effort of the exertion of the will. A remark falls from Dr. Vaughan Harley, in a recent paper on "The Value of Sugar and the effect of Smoking on Muscular Work"* in keeping with the foregoing ob-

* 'Journal of Physiology,' 1894.

servation. He noticed that if he thought about the exercise to which he was going to apply his fingers, the maximum power was obtained at the very outset. The reason of this observation is obvious. The exercise of the will caused him to take into his lungs an increased volume of air, and on that account he was the better prepared for the exercise the moment it was commenced.

Professor Ramsay, of University College, kindly consented to submit to the experiment, and others were made on myself and Mr. Floris. These experiments all give the same result, that breathing under the influence of the will is a phenomenon attended with an increased volume of air breathed, and a greater volume of carbonic acid expired.

The results of these experiments are given in the following table:—

Breathing under the Influence of the Will.

Per minute.

Persons under experiment.	Vol. air expired normal.	Vol. air expired under will.	CO_2 expired normal.	CO_2 expired under will.	Time the will was applied.
	litres	litres	grams c.c.	grams	m. sec.
Prof. Ramsay.	3·698	4·078	148·0	168·9	2 35
Author.......	3·910	4·345	182·3	203·5	
"	4·173	4·478	171·4	188·1	2 25
"	3·948	4·160	156·8	169·3	2 18
Mr. Floris....	3·386	4·500	166·8	205·4	
Author.......	4·359	4·958	186·0	205·6	2 0
Mr. Floris....	3·472	3·747	185·4	200·0	1 0
Author.......	4·347	5·362	190·9	214·0	4 0
Means......	3·912	4·453	173·4	194·3	—

Mean increase in vol. air expired per min. .... 0·541 litre.
Mean increase in CO_2 expired " .... 20·9 c.c.

The well known interesting experiment of Professor Mosso, of Turin, might be here recorded, which demonstrates in the most conclusive manner that the brain, from fatigue, loses its power to excite muscular contraction; this experiment also favouring the conclusion that brain work is attended with combustion.

The following is a summary of the present inquiry:—

There are four distinct forms of breathing, which include every variety of respiration.

1. Natural breathing in the state of repose.
2. Forced breathing:—a voluntary increased action of the thoracic

muscles attended with fatigue and with an expiration of carbonic acid increased beyond the normal. This, however, is due mainly to the displacement of carbonic acid present normally in the blood, a small proportion of CO_2 only being the result of the work done by the action of the muscles concerned in the forced respiration. A sudden return from forced to normal breathing in repose is attended with an involuntary double reaction, the first being a respiratory pause, and the second a slight increase of the respiration more or less marked according to the intensity of the first reaction and merging into natural breathing.

3. Respiration *under exercise*, exhibiting characters shown in the tracings, and in other respects described in a previous paper.

4. Breathing *in a state of muscular repose while under the influence of a strong effort of volition.* The characters of this form of respiration partake of breathing *under muscular exercise* and of *forced breathing.* Like breathing during exercise, the volume of air respired is increased, and the action of the respiratory muscles is automatic and unattended with any fatigue, while there is an elimination of an increase of CO_2. Like forced breathing, on releasing the influence of the will there is a slight reaction or pause, but it is distinctly less marked than after forced breathing, and the following after stage observed in forced breathing, is barely, if at all perceptible. From these circumstances it is concluded, though as it were from circumstantial evidence, that volition strongly exerted is productive of the formation of carbonic acid.

The second form of breathing, or forced expiration, includes sneezing, sighing, and yawning.

The third form of breathing, or under exercise, includes what may be called vocal breathing, or reading, talking, singing, weeping, laughing, shouting, and coughing. In these instances there is but little or no CO_2 absorbed in the blood as it is given out as the exercise proceeds.

The fourth form of breathing may be considered as including every kind of mental exertion.

Finally, the different forms of breathing may assist or clash with each other. Thus forced breathing assists breathing under exercise, especially when repose follows exercise.

Forced respiration may clash with vocal respiration as shown by the difficulty experienced in talking or singing immediately after forced breathing.

Appendix.

An explanation is wanted with reference to the production of heat required for the labour of forced breathing. It might be objected in accordance with the statement of Hirn, in his book on the "Mechani-

cal Theory of Heat," that the heat emitted by an animal should be measured by the amount of oxygen consumed, while I look upon this heat as due exclusively to the CO_2 produced.

The fact contained in my last paper that the mean volume of oxygen absorbed (not transformed into CO_2) in exercise, is the same as that absorbed in the state of rest, shows clearly that the oxygen absorbed is not concerned in the production of heat necessary for muscular exercise.

By an inspection of the following table, it will be clearly seen that

Oxygen absorbed and Carbonic Acid Expired at Rest, Normal and Forced.

The Author under Experiment.

	Normal in repose.			Under forced breathing.		
	CO_2 expired.	O absorbed.	O consumed.	CO_2 expired.	O absorbed.	O consumed.
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
	203·8	55·6	259·4	311·8	nil	352·0
	192·1	34·9	227·0	262·1	11·2	273·3
	191·1	34·6	225·7	245·6	14·0	259·6
	159·7	47·9	207·6	204·0	45·6	249·6
	200·2	45·0	245·2	240·9	6·4	247·3
Means ..	189·2	43·6	233·0	253·0	15·4	272·0

Mr. Floris under Experiment.

	CO_2 expired.	O absorbed.	O consumed.	CO_2 expired.	O absorbed.	O consumed.
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
	209·6	35·7	245·3	251·1	3·1	254·2
	215·4	39·0	254·4	270·0	35·8	305·8
	187·8	12·7	200·5	229·6	nil	225·5
	193·2	16·9	210·1	248·0	16·6	264·6
	189·5	10·1	199·6	234·4	5·6	240·0
Means ..	199·1	22·9	222·0	246·6	12·2	258·0

the oxygen "absorbed" (not transformed into CO_2) under forced breathing was very much less than that absorbed in natural respiration, instead of being in excess, as might have been expected if the oxygen "absorbed" was concerned in the production of the heat required for the labour of forced breathing. Subsequent investigation showed that the reduction of the oxygen "absorbed" in forced breathing was due to the fact that, although the CO_2 had returned to the normal in the above experiments, still the O "absorbed" was short

of its normal figure; by prolonging the experiment this figure was recovered, or very nearly so.

The following is a list of the curves on the charts which accompany this paper:—

Forced Breathing.

The Author.		Normal, forced, and reaction.

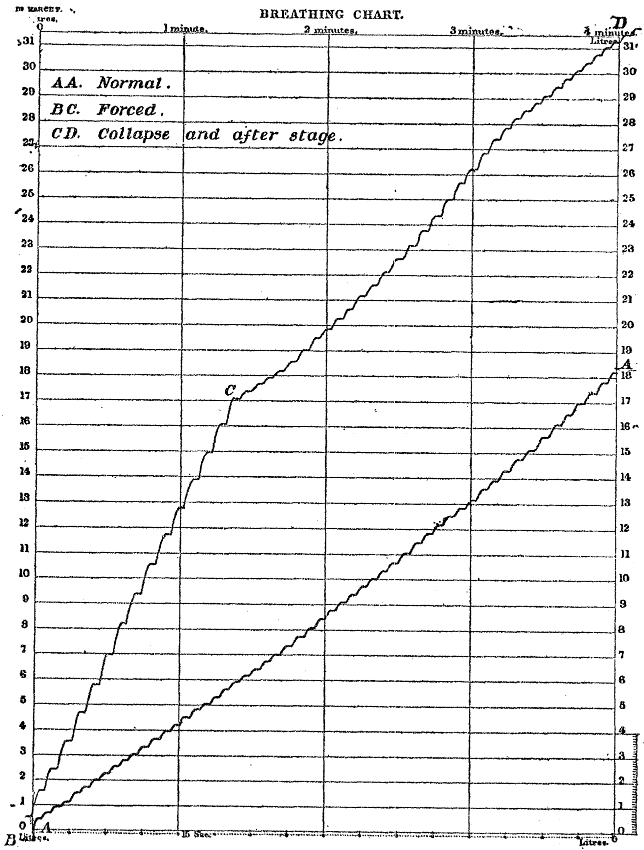
Breathing under Exercise.

The Author,	1.	Normal, exercise, and after stage, and forced to compare with exercise.
Mr. Floris,	2.	Normal, reading aloud, and after stage.
,,	3.	Normal, laughing, and after stage.

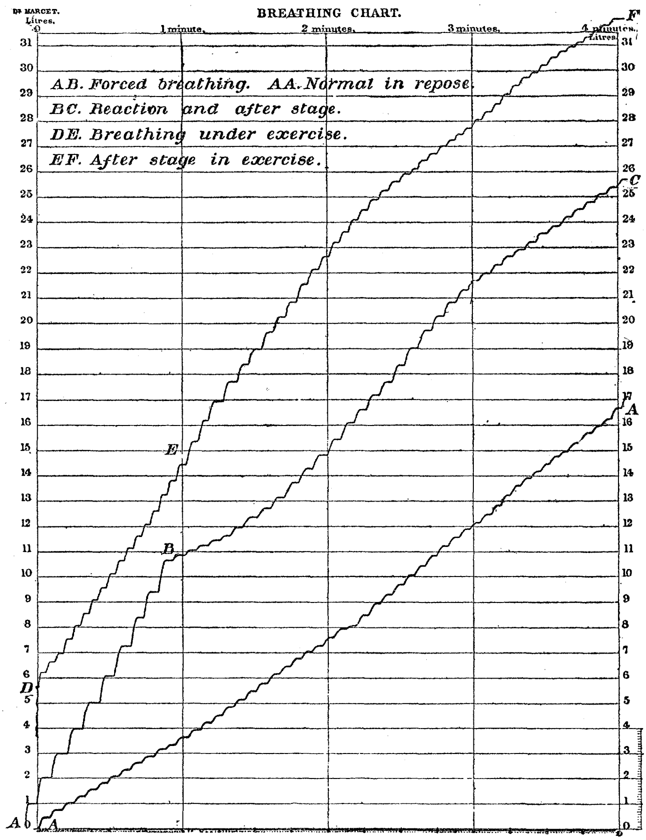
Breathing under the influence of the Will.

Mr. Floris,	1.	Normal, will, and after stage. Forced breathing to imitate will and after stage.
The Author,	2.	Normal, will, and after stage, exercise and after stage.

Forced Breathing.

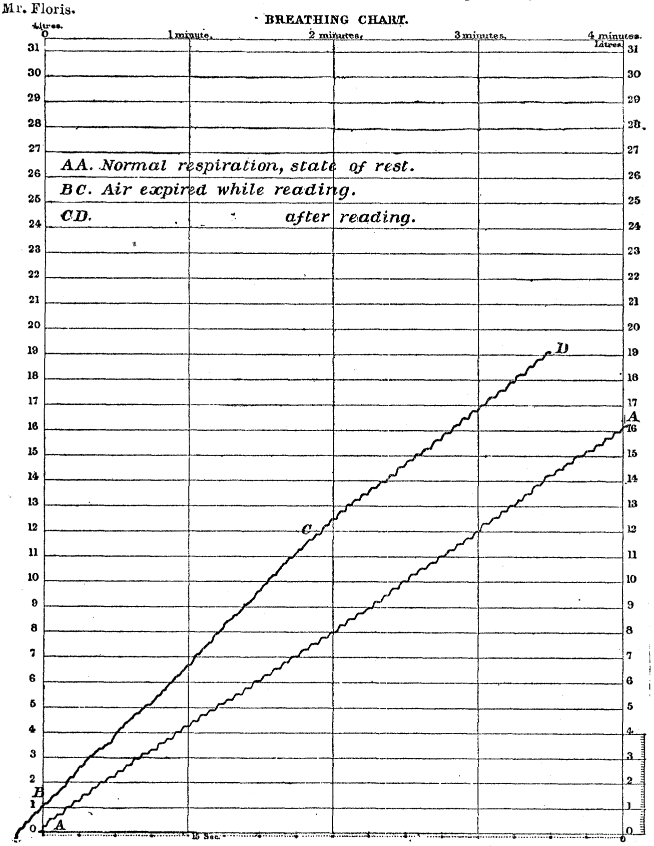


Breathing under Exercise (stepping), compared with Forced Breathing.

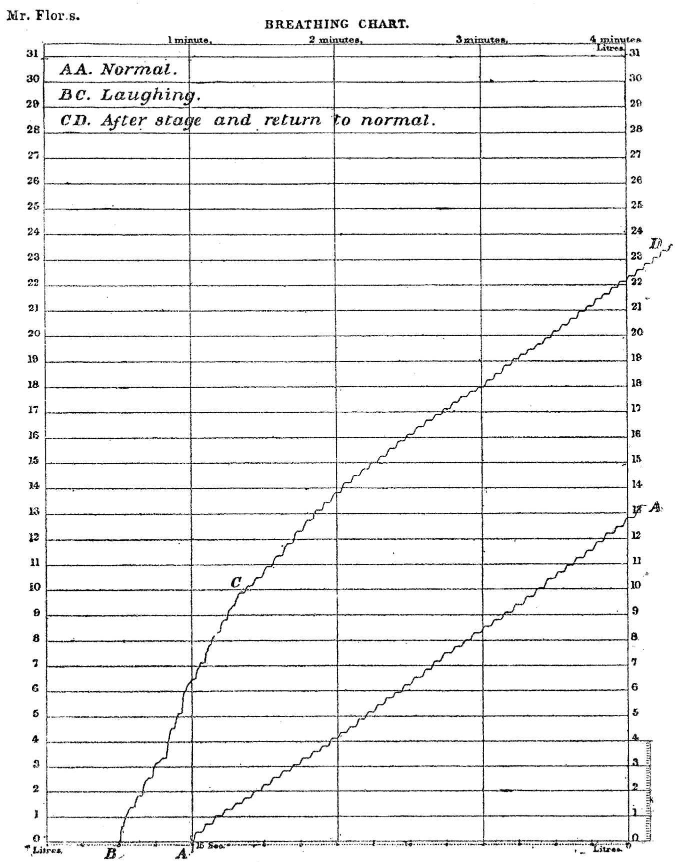


2.—Breathing under Exercise (reading aloud)

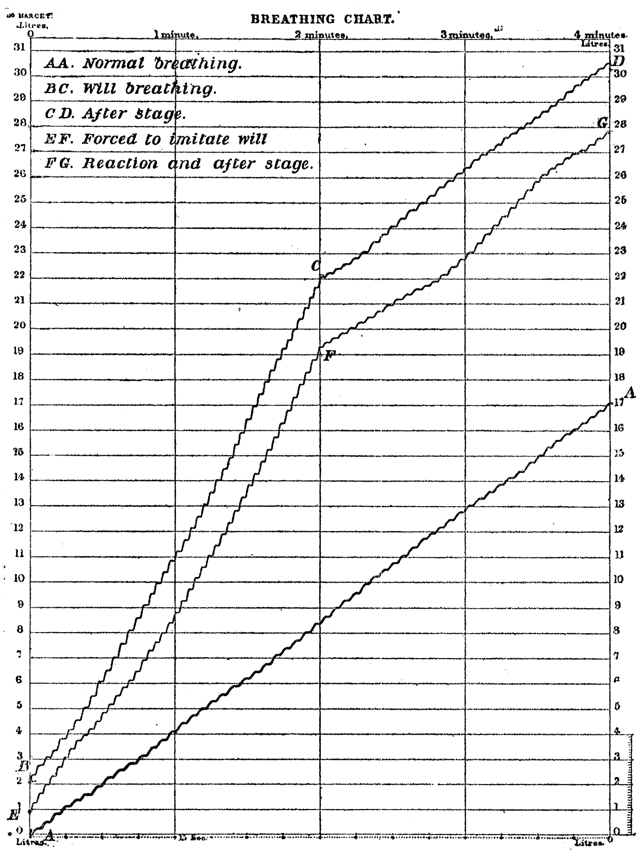
Mr. Floris.



3.—Breathing under Exercise (laughing).



1.—Breathing under the Influence of the "Will," with Forced Breathing to imitate "Will."



2.—Breathing under the Influence of the Will, with Breathing under Exercise.